NASA WG3 MMOD Protection Summary

33rd Interagency Space Debris Coordination Committee (IADC)
March-April 2015

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Summary of MMOD Protection Activities

- **International Space Station (ISS)**:
  - Assessed risk change to ISS hardware & EVA suits from ORDEM 3.0 (charts 3-5)
  - Identified MMOD damage in on-orbit photos of ISS radiators and solar arrays (charts 6-9)
  - Continue planning on-orbit inspection of visiting vehicle thermal protection systems prior to undock
  - Continue damage detection & repair work (joint international working group)

- **Multipurpose Crew Vehicle (Orion), Commercial Crew & Resupply Vehicles**:
  - Performed post-flight MMOD damage inspections of SpaceX Dragon cargo vehicle after ISS resupply missions, and Orion vehicle after exploration flight test 1 (charts 10-15)
  - Performed risk assessments and hypervelocity impact tests to verify compliance to MMOD requirements

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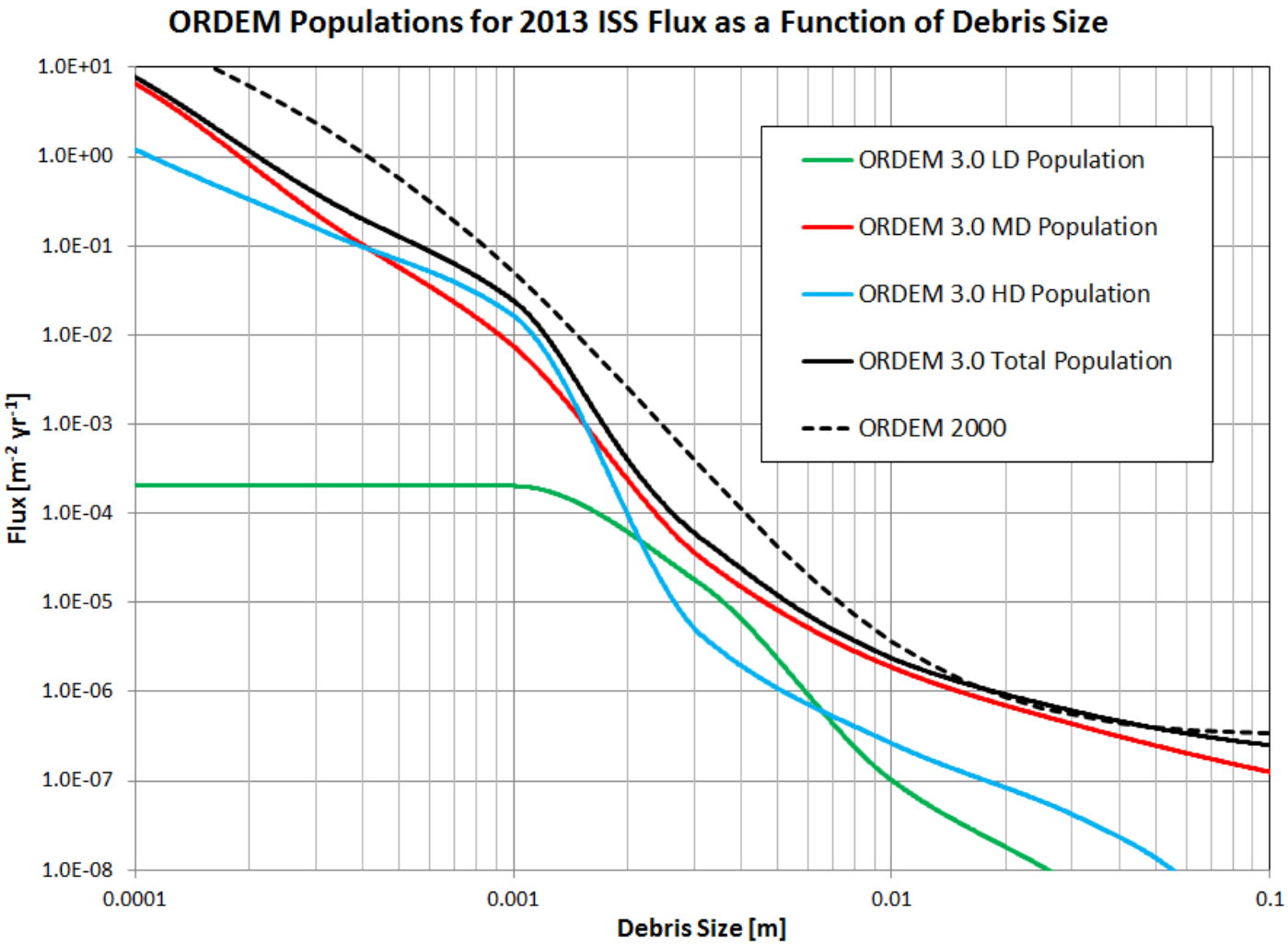
Material Distributions - ISS



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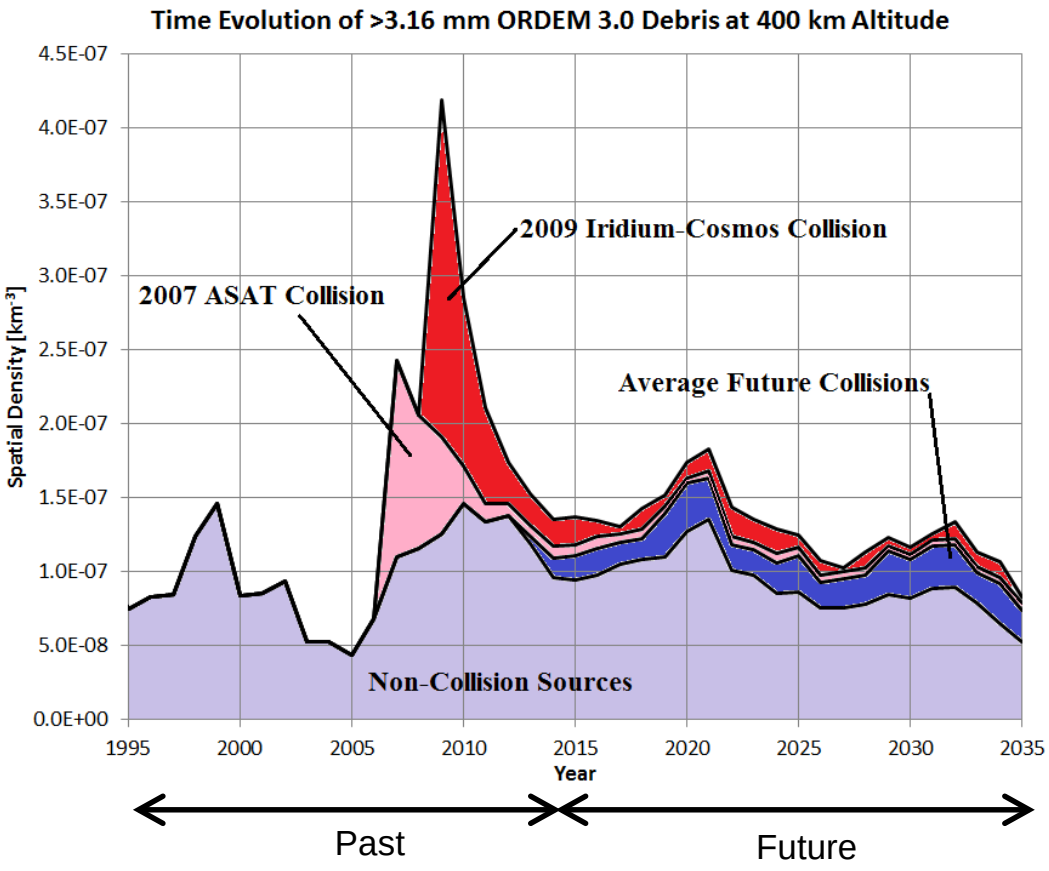
Past Environment vs. Future Risk; > 3 mm ISS altitude (400 km)



- **Predicted spatial density in the future is somewhat higher than pre-2007 measured values even though the contribution from the two collisions has dropped to very low levels.**
- **Part of the increase is due to averaging 120 different future "realities."**
  - Each future Monte Carlo environment has 0, 1, 2, or more future collisions or explosions at "random" times.
- **The future level is an accurate representation of the risk to ISS.**

Note: Public release version will not produce data prior to 2010

ISS MMOD penetration risks with ORDEM 3.0 debris model (Bumper code results)

- Addition of steel particles in ORDEM 3.0 debris flux increases overall risk to ISS compared to results using previous debris model (ORDEM 2000)
  - Overall trend is for lightly shielded items to have higher risk and better protected items have lower risk

Risk of penetration over 10-years
1/2015 – 12/2024
(penetration = hole in crew module pressure shell, failure of external pressurized tanks & CMGs)

	ORDEM 3.0 + MEM	ORDEM 2000 + MEM
ISS Risk	34%	25%
ISS PNP (PNP=1-Risk)	0.662	0.751

Note: ORDEM = orbital debris model, MEM = meteoroid model
PNP = probability of no penetration

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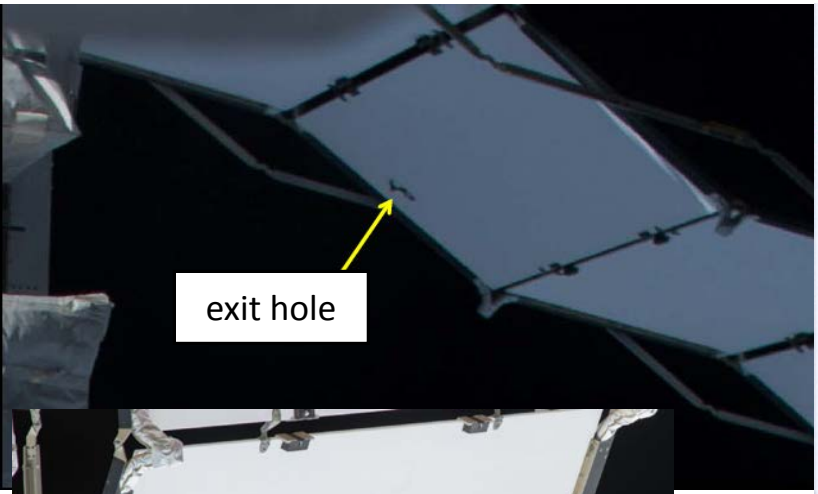
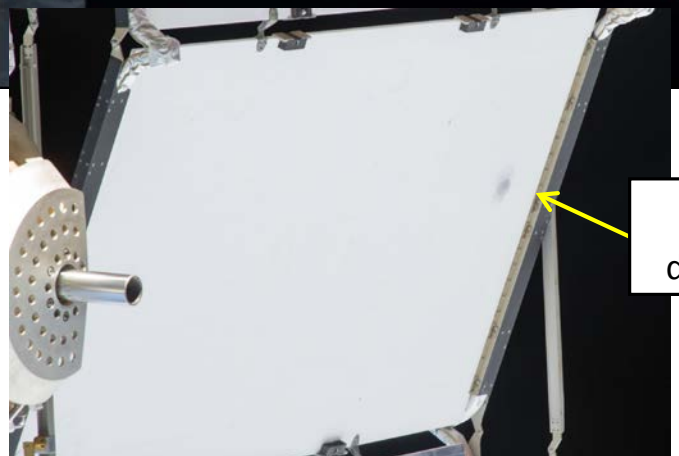
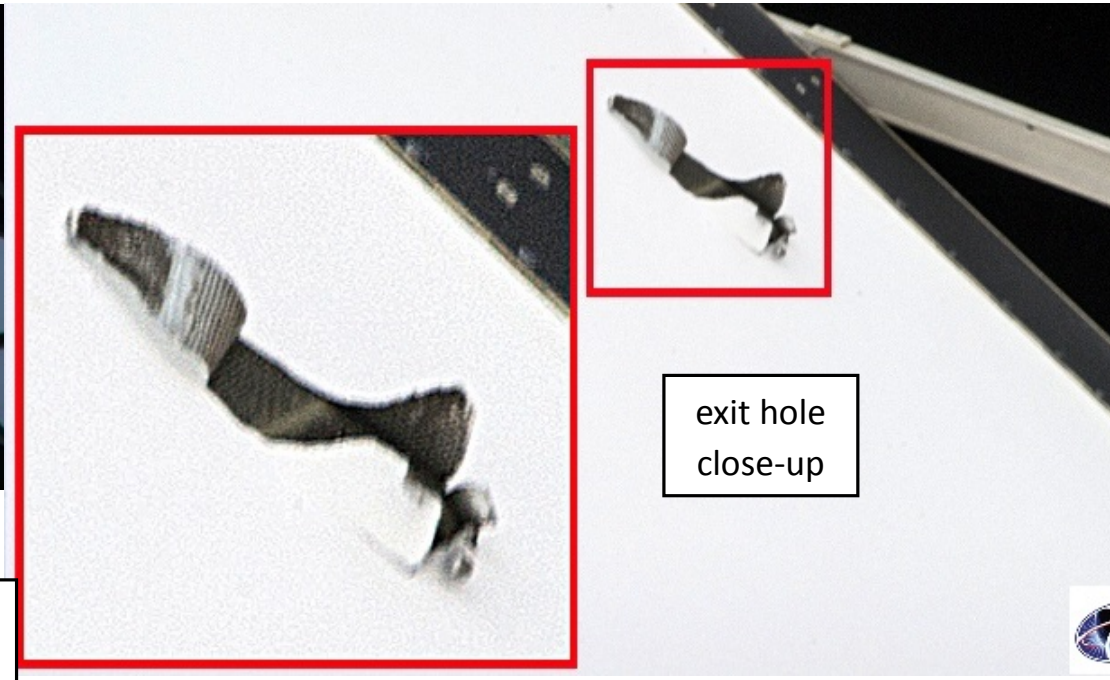
MMOD damage on ISS photovoltaic (PV) radiator

- Indication found on 30 June 2014 (Port 4 truss PV radiator)
- Exit hole shown below measures 5” x 3.9” (13 cm x 10 cm)
- Entry hole on opposite side is 0.7” x 0.5” (1.8 cm x 1.3 cm)
- Initial estimated MMOD particle size causing damage: 4 mm to 5 mm dia.







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Ground hypervelocity impact test MMOD damage compared to P4 photovoltaic radiator damage

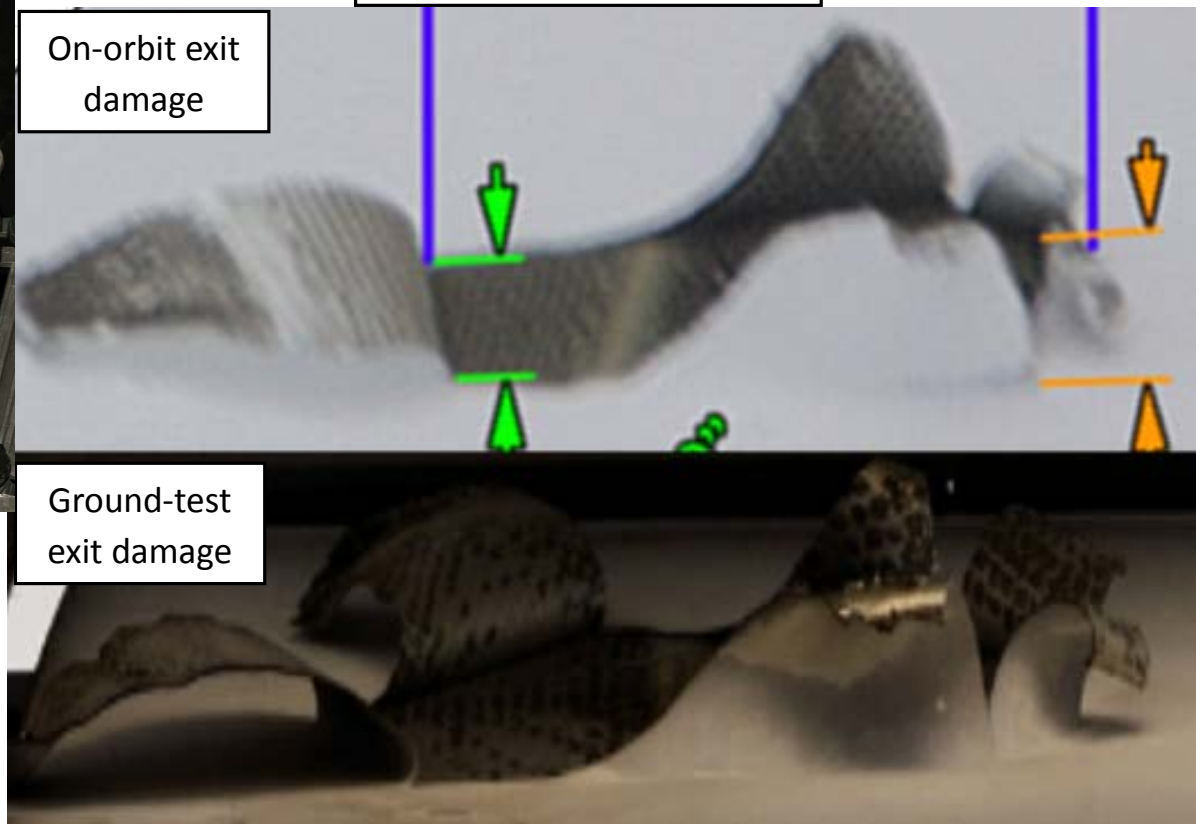
- Exit hole damage from 4.5 mm diameter aluminum spherical projectile at 7.08 km/s and 50 deg impact angle (angle from target normal) compares fairly well with actual damage

Ground-test entry damage

Ground-test exit damage

Comparison of exit damage

On-orbit exit damage



Ground-test exit damage

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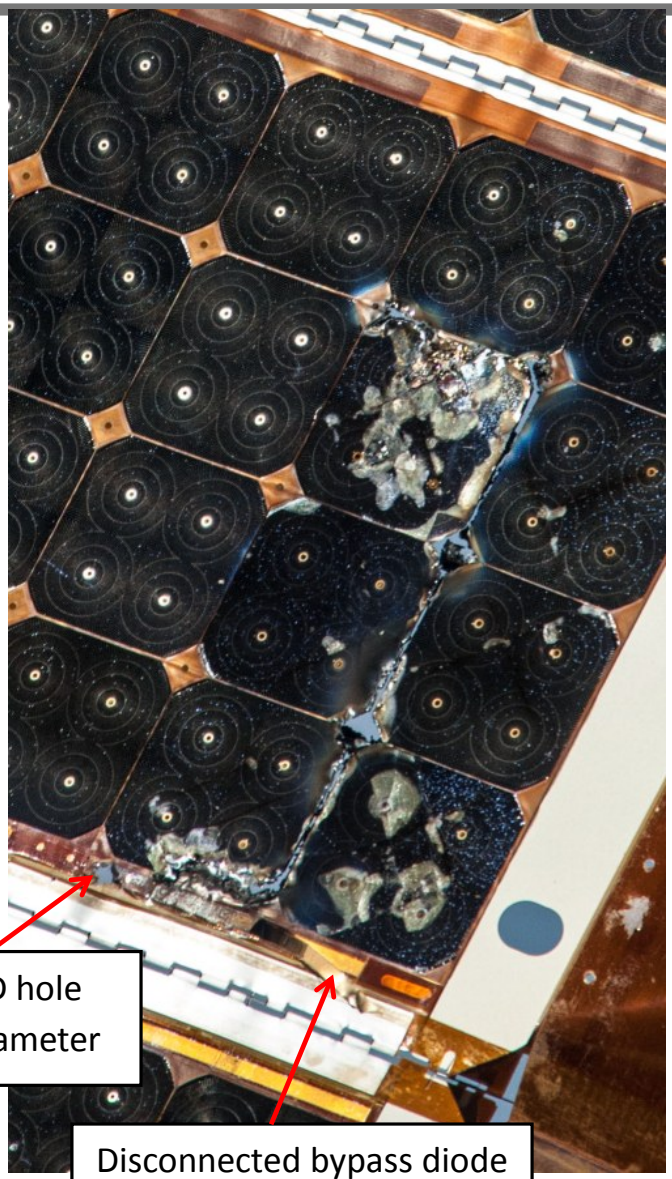
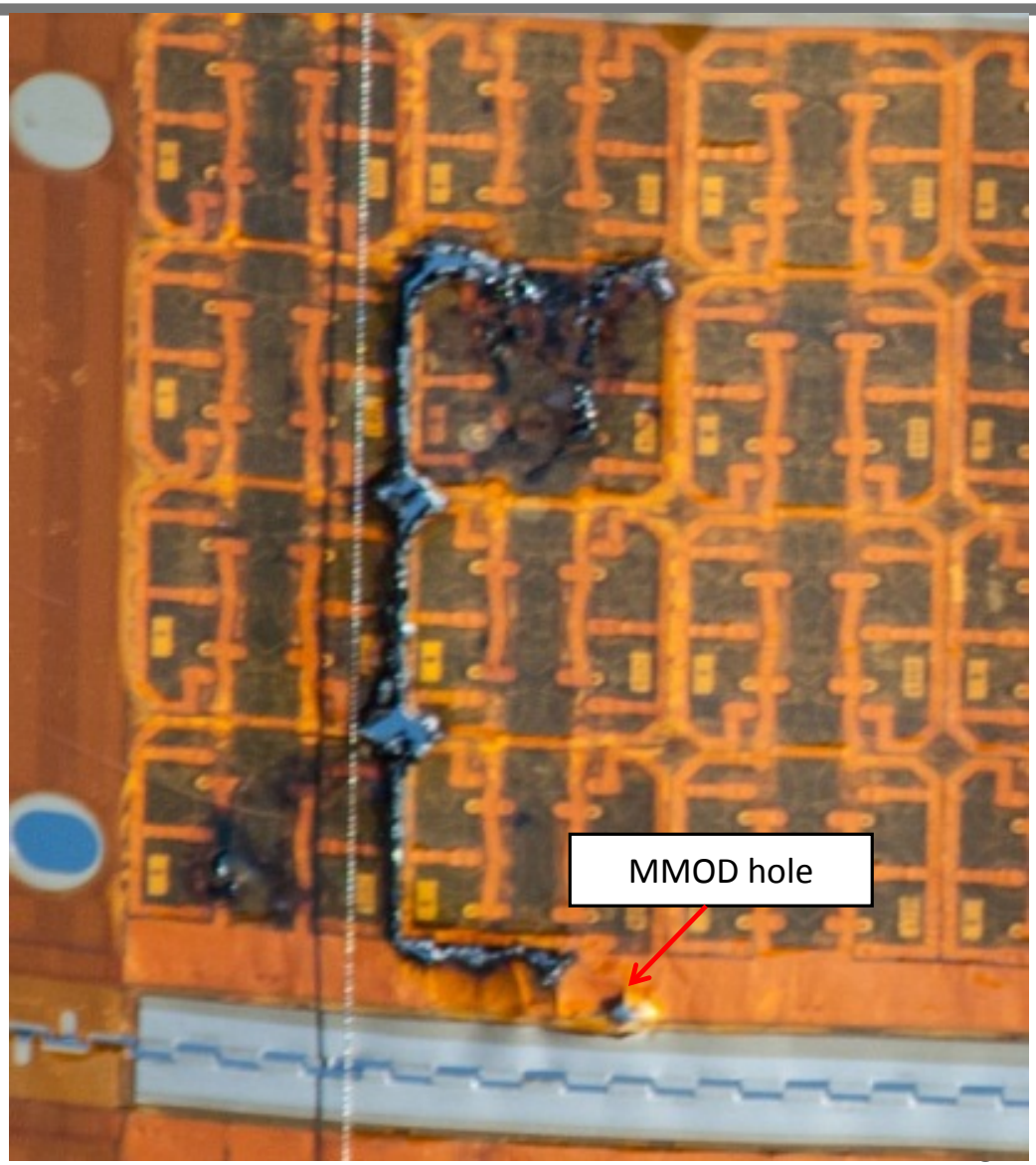
ISS Solar Array Damage

Solar array 3A, panel 58





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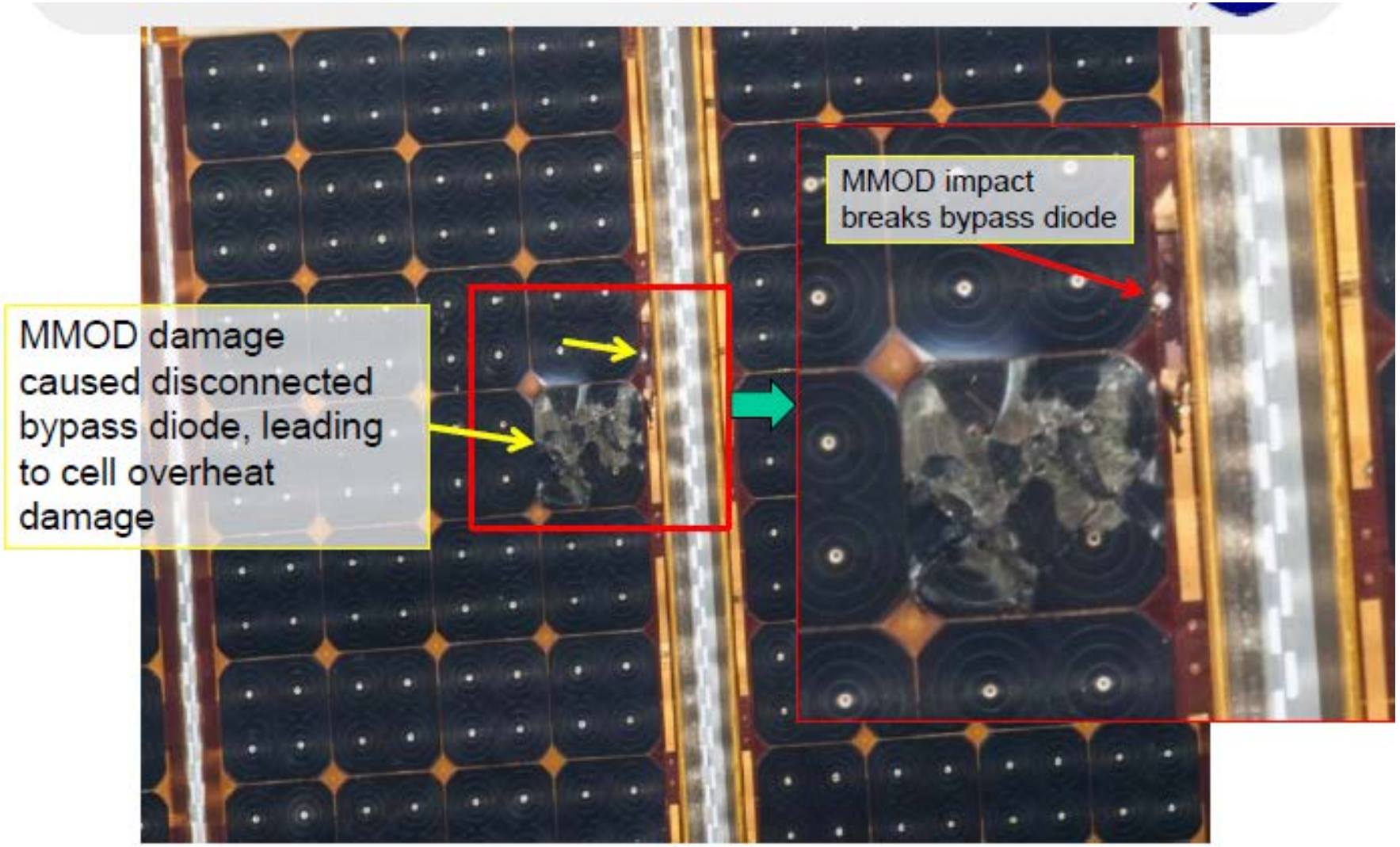
ISS Solar Array Damage

Solar array 2A, panel 66



EFT-1 Post Flight MMOD Inspection

- Current Status
  - Inspection performed on back shell panels, base heat shield, crew module windows and docking hatch
  - 6 damages identified on back shell TPS that are potentially from MMOD
    - Removed tiles with 5 of these 6 damages for non-destructive evaluation (NDE) and scanning electron microscopy (SEM)
  - 41 pits identified on crew module and docking hatch windows
- Forward Work
  - NDE characterization of selected MMOD damage sites
  - Scanning Electron Microscopy of MMOD damage sites
  - Final disposition of damage sites and comparisons to impact predictions
  - Documentation

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EFT-1 Post Flight MMOD Inspection

Surface Type	ROI #	Capsule Region	Material	Feature Size (mm) Length	Width	Depth	Sample	Preliminary Disposition
TPS	4	Panel A, Tile 33	AETB-8	0.51	0.50	0.50	intact extraction of tile	possible MMOD
TPS	7	Panel C, Tile 73	AETB-8	1.29	1.10	0.05	intact extraction of tile	possible MMOD
TPS	20	Panel H, Tile 144	AETB-8	0.63	0.56	0.54	intact extraction of tile	possible MMOD
TPS	23	Panel I, Tile 45	AETB-8	1.18	1.15	0.60	TBD	possible MMOD
TPS	24	Panel F, Tile 45	AETB-8	1.06	1.02	1.02	intact extraction of tile	possible MMOD
TPS	25	Panel A, Tile 8	AETB-8	1.88	1.27	0.70	intact extraction of tile	possible MMOD

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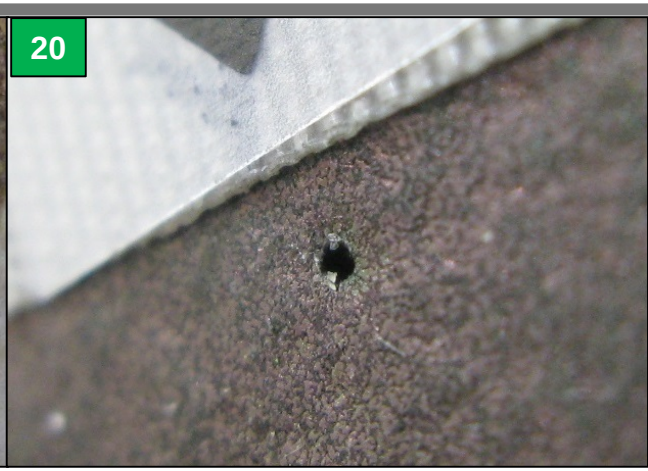
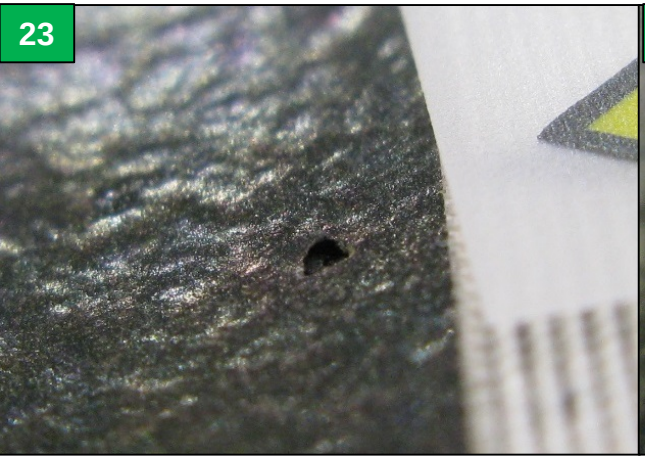
EFT-1 Post Flight MMOD Inspection

Panel A, Tile 33
Feature Size = 0.51 x 0.50 mm
Depth= 0.50 mm

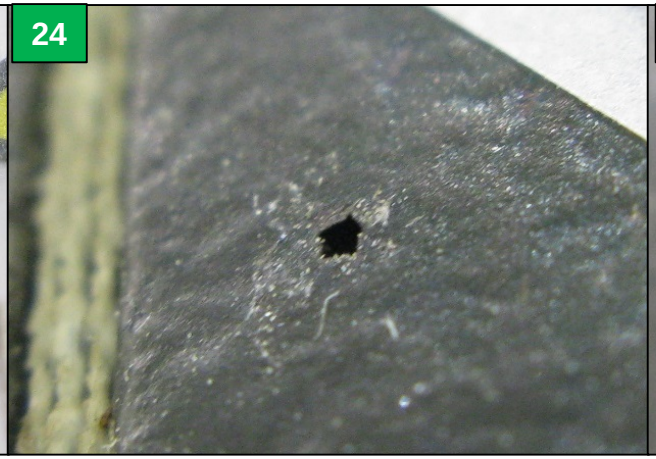
Panel C, Tile 73
Feature Size = 1.29 x 1.10 mm
Depth= 0.05 mm



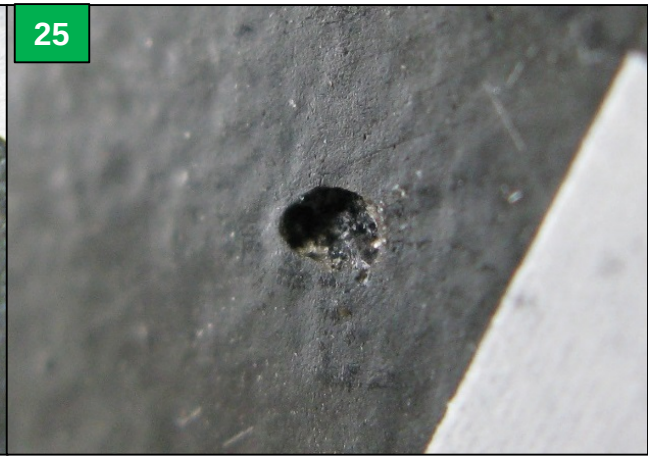
Panel H, Tile 144
Feature Size = 0.63 x 0.56 mm
Depth= 0.54 mm



Panel I, Tile 45
Feature Size = 1.18 x 1.15 mm
Depth= 0.60 mm



Panel F, Tile 45
Feature Size = 1.06 x 1.02 mm
Depth= 1.02 mm



Panel A, Tile 8
Feature Size = 1.88 x 1.27 mm
Depth= 0.70 mm

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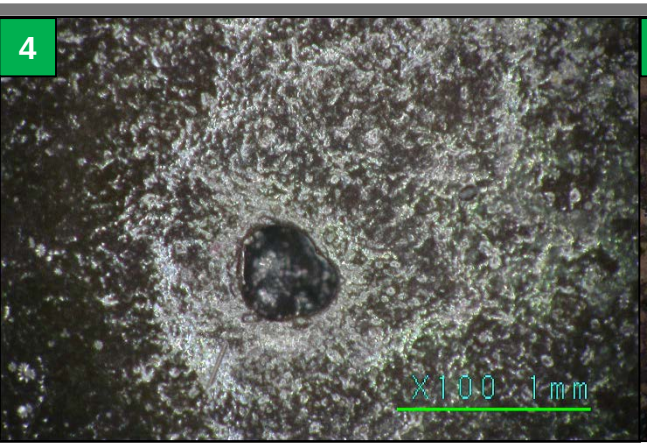
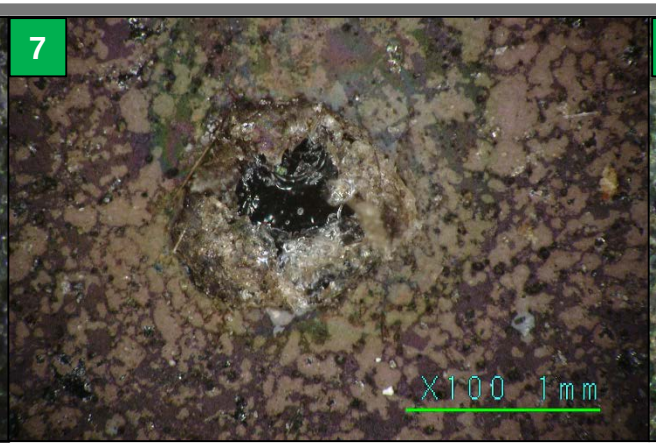
EFT-1 Post Flight MMOD Inspection

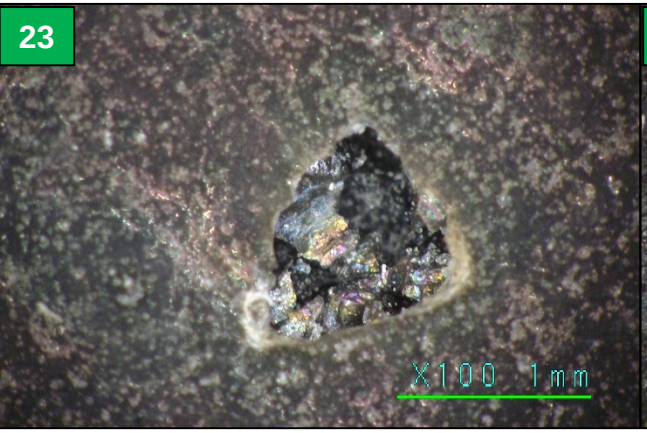


Panel A, Tile 33
Feature Size = 0.51 x 0.50 mm
Depth= 0.50 mm

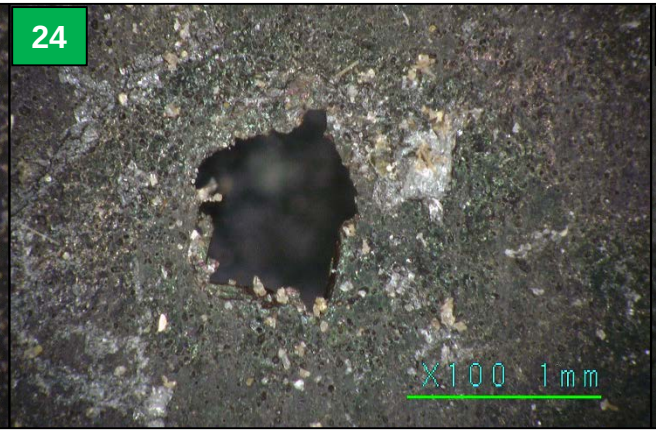


Panel C, Tile 73
Feature Size = 1.29 x 1.10 mm
Depth= 0.05 mm

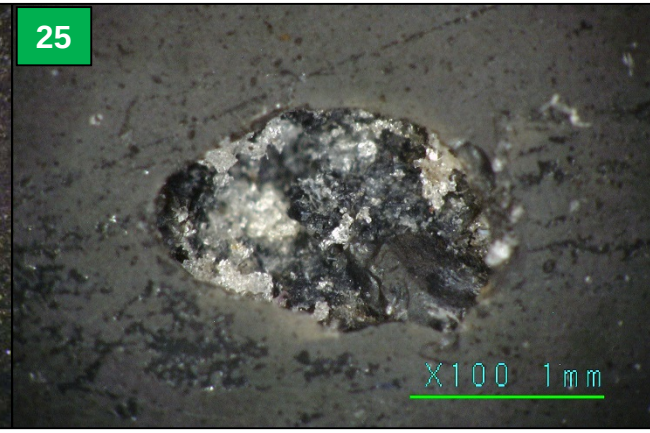
Panel H, Tile 144
Feature Size = 0.63 x 0.56 mm
Depth= 0.54 mm



Panel I, Tile 45
Feature Size = 1.18 x 1.15 mm
Depth= 0.60 mm



Panel F, Tile 45
Feature Size = 1.06 x 1.02 mm
Depth= 1.02 mm



Panel A, Tile 8
Feature Size = 1.88 x 1.27 mm
Depth= 0.70 mm

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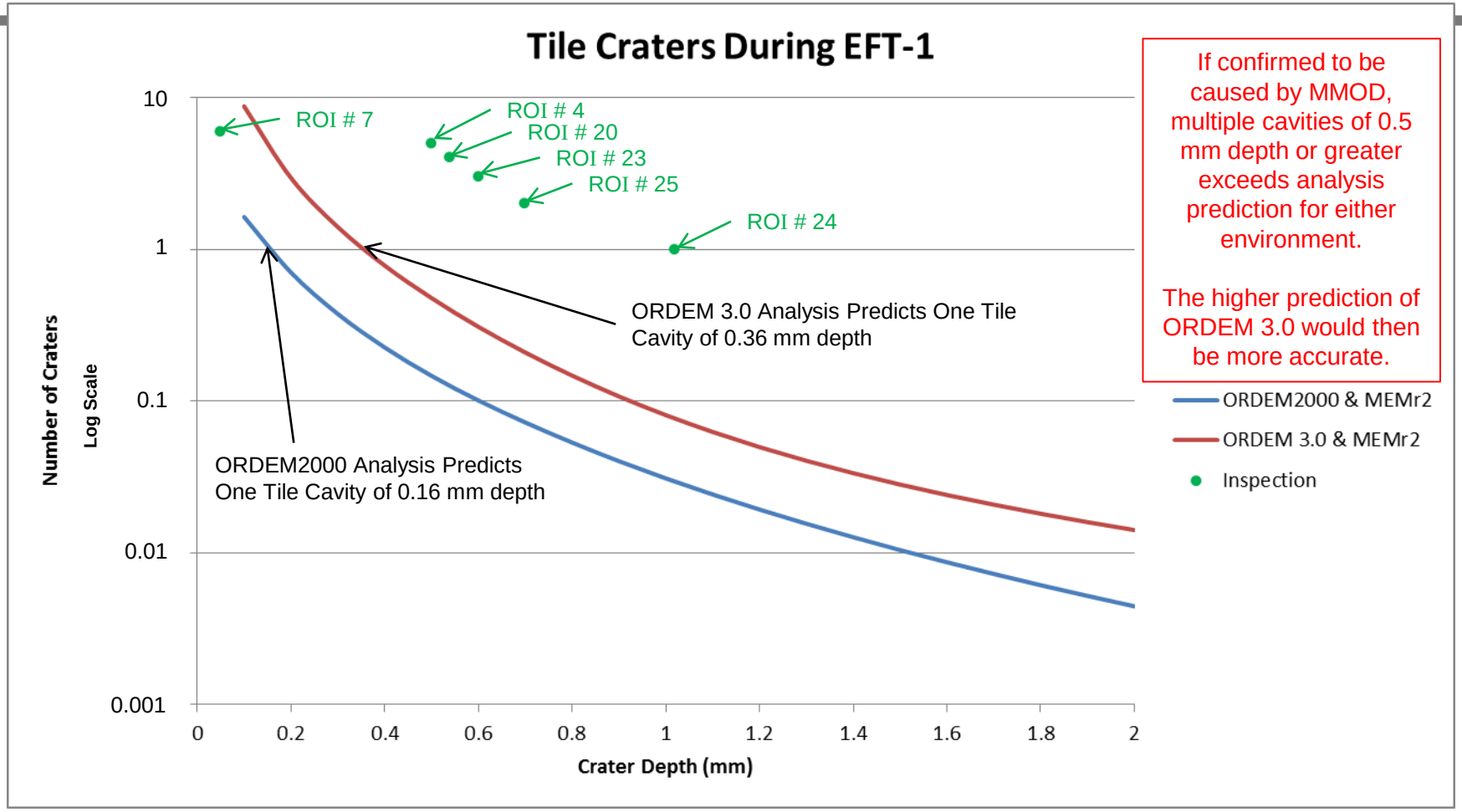
Backshell Tile Damage Predictions compared to Observations



Using ORDEM2000
Smallest damage sizes are ~70% OD / ~30% MM
Medium damage sizes are ~85% OD / ~15% MM
Largest damage sizes are ~90% OD / ~10% MM

Using ORDEM 3.0
All damage sizes are ~95% OD / ~5% MM

ROI # 7	ROI # 4	ROI # 20	ROI # 23	ROI # 25	ROI # 24
0.05 mm	0.50 mm OD3: 38% OD2k: 14%	0.54 mm OD3: 34% OD2k: 12%	0.60 mm OD3: 27% OD2k: 10%	0.70 mm OD3: 19% OD2k: 7%	1.02 mm OD3: 7% OD2k: 3%

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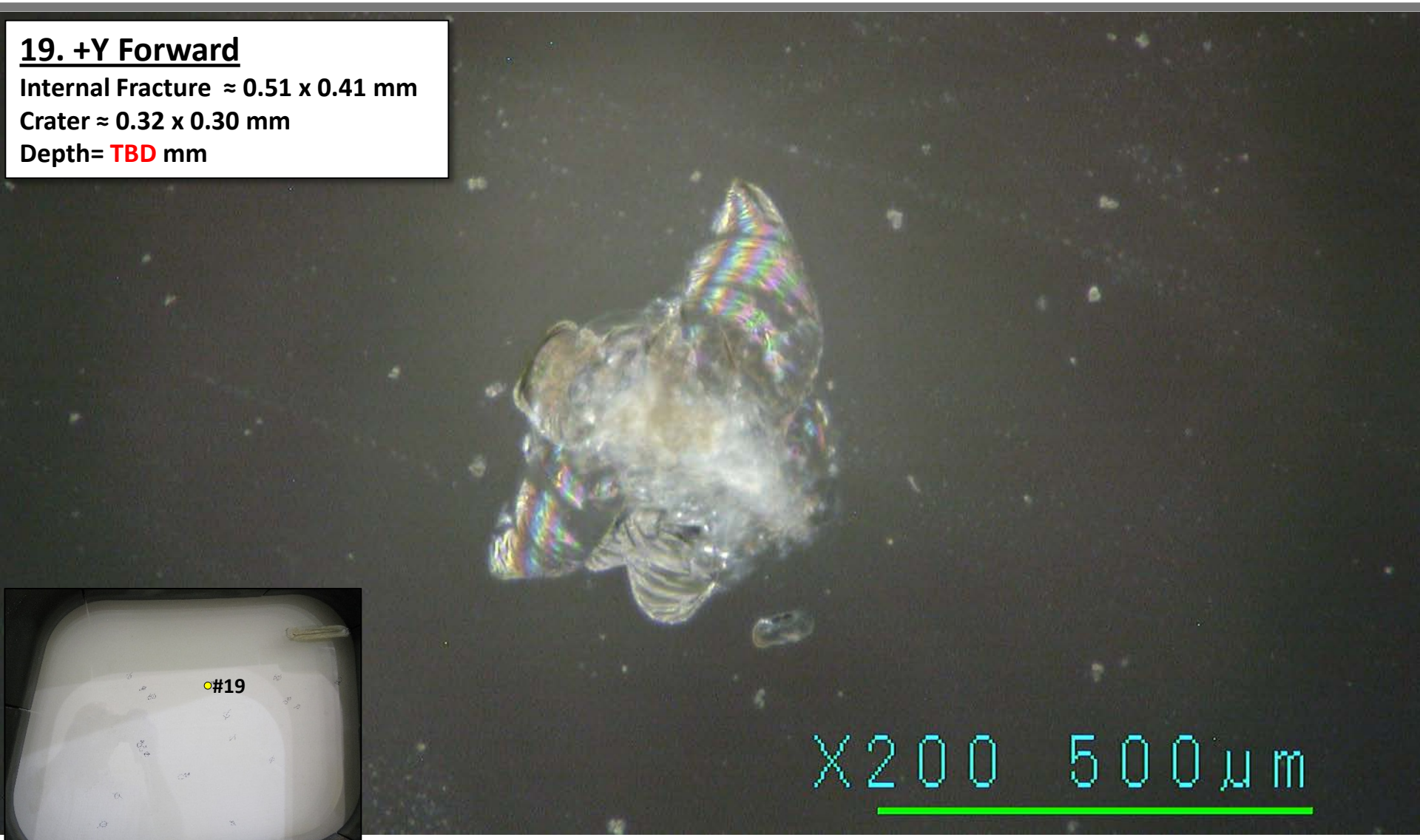
EFT-1 Post Flight MMOD Inspection Window impact

19. +Y Forward

Internal Fracture ≈ 0.51 x 0.41 mm
Crater ≈ 0.32 x 0.30 mm
Depth= TBD mm



Backup Charts

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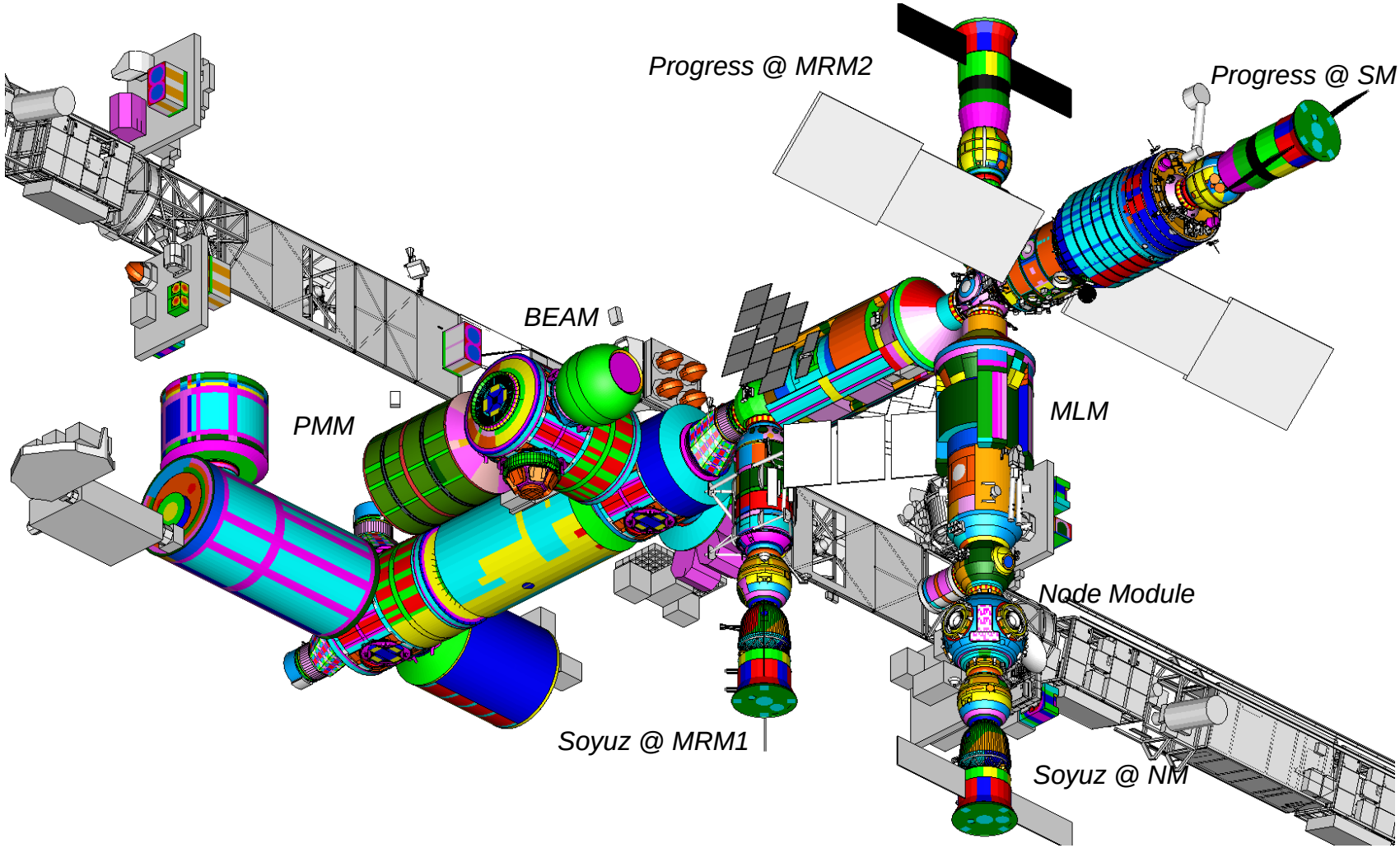
ISS *Bumper* finite element model

after addition of MLM, Russian Node, and BEAM modules, and after PMM relocation



Each color represents a different MMOD shield configuration
(~500 different shields protect ISS modules and external pressure vessels)